

WHAT CAN YOU DO WITH A RETURNED SAMPLE OF MARTIAN DUST?

M.E. Zolensky and K. Nakamura-Messenger; Astromaterials Research and Exploration Science, NASA Johnson Space Center, Houston, TX 77058 USA (michael.e.zolensky@nasa.gov).

Stardust PET: A major issue that we managed to successfully address for the Stardust Mission was the magnitude and manner of preliminary examination (PET) of the returned samples [1], which totaled much less than 1 mg. Not since Apollo and Luna days had anyone faced this issue, and the lessons of Apollo PET were not extremely useful because of the very different sample masses in this case, and the incredible advances in analytical capabilities since the 1960s. After *considerable* discussion with the Curation and Analysis Planning Team for Extraterrestrial Materials we finally all agreed that we would make the 9 month long sample PET as comprehensive as possible, and to also be as inclusive as reasonable with respect to the PET team. We divided the PET effort into six parallel and interrelated efforts: (1) Bulk Composition, (2) Mineralogy and Petrology, (3) Organics, (4) Optical Properties, (5) Isotopes, and (6) Small Craters in Aluminum. All qualified scientists were invited to join any number of these groups, provided they met some minimal background requirements and agreed to group publication all PET results in *Science* (see Brownlee et al., 2006 [1] and all the adjacent papers). Initially we limited PET participation to PhDs with prior experience with analysis of astromaterials. As the effort progressed these rules were relaxed to permit new techniques to be employed and new expertise to be involved. An attractive result of this exercise was the entry of numerous new groups into the astromaterials field and the formation of very powerful new collaborations.

The PET was designed to proceed from the least invasive analyses through marginally destructive ones, and finally to some completely destructive procedures, to maximize the data harvest from minimal sample mass [2]. Thus we began many analysis trees using synchrotron X-ray fluorescence (SXRF), synchrotron tomography (SCT), and/or scanning

transmission X-ray microscopy (STXM) of entire keystone tracks, before actually removing individual grains from the tracks for analysis. These analyses enabled us to focus later characterization efforts on the most interesting captured grains, that would then be removed from the aerogel. We did not always have the time to follow this incremental analytical protocol during PET, but it was a model we followed whenever possible. For these separated grains we usually performed Vis-IR spectroscopy before proceeding to ultramicrotomy, isotopic, mineralogic or organic analyses of sections of grains. Table 1 lists the most commonly applied analytical techniques for nanogram-sized astromaterials, along with their relative, general level of sample destructiveness (modified after [2]). The techniques actually applied to Stardust samples during PET are underlined. Considering the short time (9 months) available for sample PET the range of applied analyses is remarkable, reflecting the value of the returned samples and the depth and dedication of the sample community. When we began to test silica aerogel as a capture media for cometary coma grains in the mid-1980s, the list of available analytical techniques was far shorter than what it is today, and the roster of nanogram-able sample analysts in the astromaterials community was far smaller. A principal value of a returned sample over what may be accomplished remotely is that the samples can be reanalyzed as new techniques are developed and new ideas and hypotheses are proposed. As long as we continue to take good care of dust-sized samples, we can expect far more and improved analyses to be made of them in the coming decades.

References: [1] Brownlee et al. (2006) *Science* **314**, 1711-1716; [2] Zolensky et al. (2000) *Meteoritics and Planetary Science* **35**, 9-29.

Table 1. A Lengthy But Not Exhaustive Summary of Analytical Techniques Available for Nanogram-sized Samples; Analyses Performed During Stardust PET are Underlined

| <u>Technique</u> | <u>Destructiveness</u> |
|---|------------------------|
| Imaging | |
| <u>Light-Optical Techniques</u> | non-destructive |
| <u>Scanning Electron Microscopy/ Energy Dispersive Spectrometry</u> | non-destructive |
| <u>Synchrotron Tomography</u> | non-destructive |
| <u>Transmission/Analytical Electron Microscopy</u> | partially |
| <u>Scanning Transmission X-Ray Microscopy</u> | partially |
| Atomic Force Microscopy | partially |
| Force Spectroscopy | partially |
| Holographic Low-Energy Electron Diffraction | partially |
| <u>SIMS Ion Imaging</u> | destructive |

Table 1 continued

| <u>Technique</u> | <u>Destructiveness</u> |
|---|------------------------|
| Bulk and Mineral Compositional Analyses | |
| Microparticle Instrumental Neutron Activation Analysis | non-destructive |
| Synchrotron X-ray Fluorescence | non-destructive |
| XRF Tomography | non-destructive |
| Scanning Transmission X-ray Microscopy | non-destructive |
| Micro Raman Spectroscopy | non-destructive |
| Electron Microprobe Analysis | partially |
| Proton Induced X-ray Emission | partially |
| X-ray Spectroscopy | partially |
| Secondary Ion Mass Spectrometry (incl the Nano persuasion) | destructive |
| Time-of-Flight Secondary Ion Mass Spectrometry | destructive |
| Laser Ablation Microprobe- Inductively Coupled Plasma-Mass Spectrometry | destructive |
| Double Focusing Secondary Ion Mass Spectrometry | destructive |
| Resonance Ion Mass Spectrometry | destructive |
| Thermal Ionization Mass Spectrometry | destructive |
| Organic Analyses | |
| Micro Raman Spectroscopy | non-destructive |
| Fluorescence | non-destructive |
| Electron Energy-Loss Near Edge Structure | partially |
| Scanning Transmission X-Ray Microscopy | partially |
| Transmission and Reflectance IR-Vis Spectroscopy | partially |
| Optically- and Acoustically-Excited Phonon Spectroscopy | partially |
| Time-of-Flight Secondary Ion Mass Spectrometry | destructive |
| Chromatography | destructive |
| Secondary Ion Mass Spectrometry (incl the Nano persuasion) | destructive |
| Stepped Combustion and Static Mass Spectrometry | destructive |
| Two-Stage Laser Desorption/Laser Multiphoton Ionization Mass Spectrometry | destructive |
| Noble Gas and Sample Exposure History | |
| Solar Flare Track Analysis | partially |
| Double-Focusing Mass Spectrometer | destructive |
| Age Dating | |
| Laser Ablation Mass Spectrometry | destructive |
| Mineralogy and Atomic Structure | |
| Synchrotron X-ray Diffraction | non-destructive |
| X-ray Absorption Spectroscopy | non-destructive |
| Transmission IR-Vis Spectroscopy | non-destructive |
| Micro Raman Spectroscopy | non-destructive |
| Transmission Electron Microscopy | partially |
| Electron Energy-Loss Near Edge Structure | partially |
| Atomic Force Microscopy | partially |
| Electron Energy Loss Spectroscopy | partially |
| Extended X-ray Absorption Fine Structure | partially |
| X-ray Absorption Near-edge Structure | partially |
| IR-Vis Reflectance Spectroscopy | partially |
| Cathodoluminescence Microscopy and Spectroscopy | partially |
| Physical Properties | |
| Density Measurements | non-destructive |
| Atomic Force Spectroscopy | partially |
| Magnetic Force Microscopy | partially |